National Aeronautics and Space Administration

Retrieval of Relevant Forest Structure Parameters from Fusion of Radar, LiDAR, Stereophotogrammetry, and optical remote sensing data.

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Radar Advances to Accelerate Earth and Planetary Missions - Strategic Initiative Leader: Darmindra D Arumugam

Objective: Demonstrate the capability of data fusion of LIDAR, PolInSAR (Polarimetric Interferometric Synthetic Aperture Radar), and other sensors to determine canopy height and other forest structure parameters in order to aid the future development of the forest structure component of a potential Surface Topography and Vegetation Mission.

Approach and Results: Trained neural networks to estimate canopy heights above the forest floor using LVIS LIDAR RH100 canopy heights as ground truth and various combinations of sensors as inputs. Compared the accuracy achieved among the different sets of inputs to determine the relative utility of each candidate sensor.

Significance/Benefits to JPL and NASA:

1. Developed a neural network method that can be used to estimate canopy heights for a variety of future PolInSAR missions with varying instrument geometry, and forest type, that need be trained only once with airborne LIDAR with no need to obtain continuous LIDAR coverage.
2. Established that SAR backscatter measurements are useful for reducing the number of PolInSAR phase pairs needed to estimate forest canopy height.
3. Demonstrated the capability of a data fusion method to obtain canopy height measurements with similar accuracy to spaceborne LIDAR by combining information from 2 to 4 C-band and/or L-band SAR observations and a source of accurate forest floor topography.

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Best and Worse Baselines for each case
(30-m RMS canopy height error in meters vs LVIS RH100 is shown)

Scenes	RVOG (Best baseline/ Worst baseline)	Backscat Only	Covar. Only (Best/ Worst)	Backscat+ Covar (Best/ Worst)	Backscat+ SRTM+ LVIS Gnd	BS+SRTM +Covar+ LVIS Gnd (Best/ Worst)	BS+SRTM +Covar+ LVIS Treetop (Best/ Worst)
Berms	4.2/15.7	6.6	3.9/7.5	2.9/5.1	2.8	2.0/2.4	1.4/1.5
Pongara	9.2/16.7	12.1	9.7/12.9	7.0/8.9	4.1	4.0/4.3	2.9/3.4
Lope	10.6/20.0	6.8	8.8/12.0	6.6/8.3	3.5	3.5/3.8	5.3/5.5
Mondah	8.9/9.6	8.9	7.9/10.6	5.5/9.3	4.9	4.4/5.3	3.4/4.0
Rabi	9.1/20.2	8.9	6.9/9.2	6.4/7.5	4.2	4.2/4.3	4.6/5.1

Figure 1. Single UAVSAR baseline neural network forest canopy height accuracy for 5 forest scenes. Berms is arboreal forest in Saskatchewan. The other scenes are tropical forest in Gabon. Columns are defined as follows:

1. Scene name
2. RMS height error (RMSE) with respect to LVIS LIDAR RH100 canopy heights of random volume over ground model [1].
3. RMSE of neural network with backscatter inputs only.
4. With UAVSAR complex covariance inputs only.
5. With UAVSAR complex covariance and backscatter inputs.
6. With UAVSAR backscatter, SRTM heights, and LVIS ground height inputs.
7. With UAVSAR backscatter, complex covariance, SRTM height, and LVIS ground height inputs.
8. With UAVSAR backscatter, complex covariance, SRTM height, and LVIS treetop height above the ellipsoid inputs.

Summary of RH100 Estimation Errors

Results of Best Baseline Triple for Each Scene

Scene	Baseline Triple	Bias (m)	NN RMSE (m) (20 m Gaussian)	NN RMSE (m) (Full Res)	Interp. RMSE (m) (20 m Gaussian)	Interp. RMSE (m) (Full Res)
Pongara	4, 9, 5	-0.37	**5.53**	9.70	9.01	10.21
Mondah	25, 5, 3	-1.01	**4.83**	8.95	8.61	10.13
Lope	14, 8, 21	-0.62	**5.29**	9.40	11.41	12.82
Rabi	5, 47, 54	-0.76	**4.35**	8.98	6.90	8.68
Berms	5, 18, 21	0.11	**1.80**	4.26	4.77	5.55

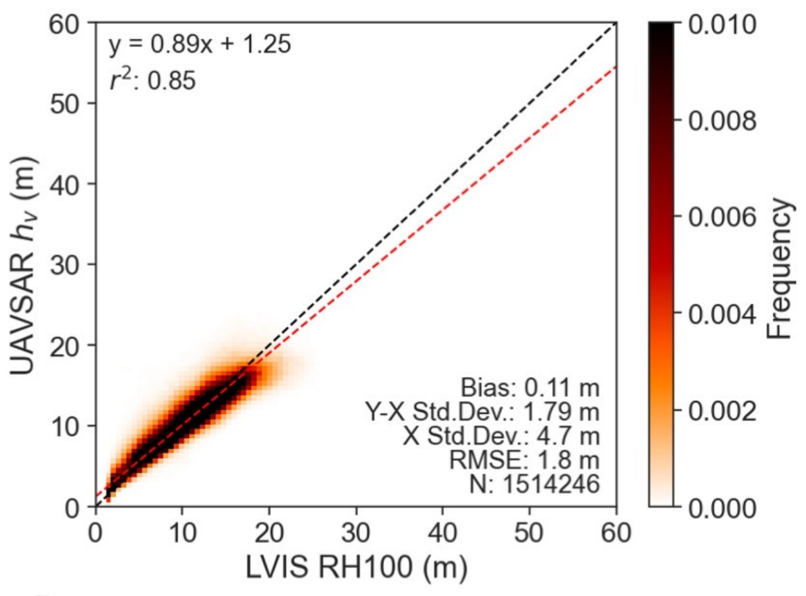
Baselines are listed in ascending order by baseline length.
NN RMSE is the error from the neural network.
Interp. RMSE is calculated from the nearest neighbor interpolated training data.

Figure 2. Triple UAVSAR baseline neural network forest canopy height accuracy for 5 forest scenes. The neural network makes use of only UAVSAR complex covariances and backscatter for all three polarizations and three baselines. Columns are defined as follows:

1. Scene name.
2. Indices of the UAVSAR baselines in the UAVSAR database.
3. Neural network bias (mean canopy height error w.r.t. LVIS RH100 canopy heights).
4. Neural network root mean square (RMS) error at 20-m resolution.
5. Neural network RMS error at full 10-m resolution.
6. RMS error attained by choosing the nearest LIDAR measurement in the neural network training set for 20-m resolution.
7. Same as 6 but for 10-m resolution.

Berms Results

Baseline Triple: (5, 18, 21)
20 m Std. Dev. Gaussian Filter



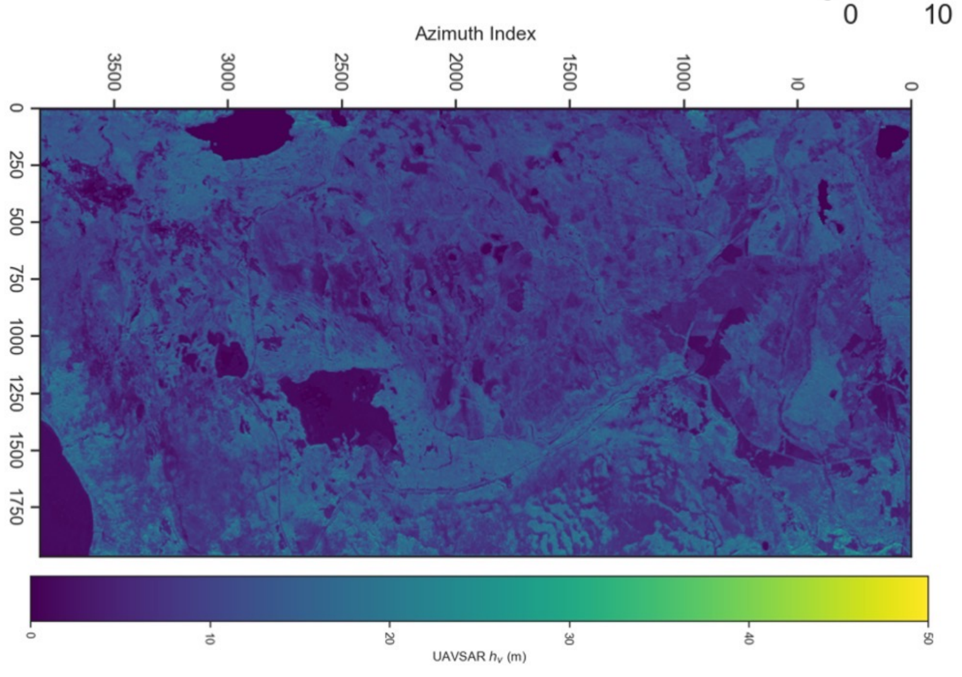


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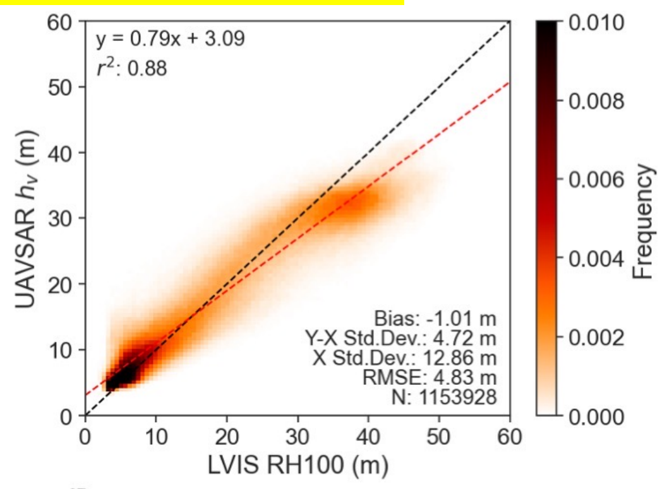
Figure 3. Triple UAVSAR Baseline Neural Network Forest Canopy Heights for Berms and Joint Histogram of UAVSAR and LVIS canopy heights. The accuracy of the neural network for Berms is 1.8-m RMS and is comparable to the RMS difference between airborne LIDAR sensors. The UAVSAR data used is L-band which is sufficient to get good canopy height estimates for forests less than 20-m in height as in the case for Berms. The relative sparseness of arboreal forest as compared to the dense tropical forest of Gabon may also play a role in explaining why UAVSAR does so much better for Berms.

Mondah Results

Baseline Triple: (25, 5, 3)
20 m Std. Dev. Gaussian Filter



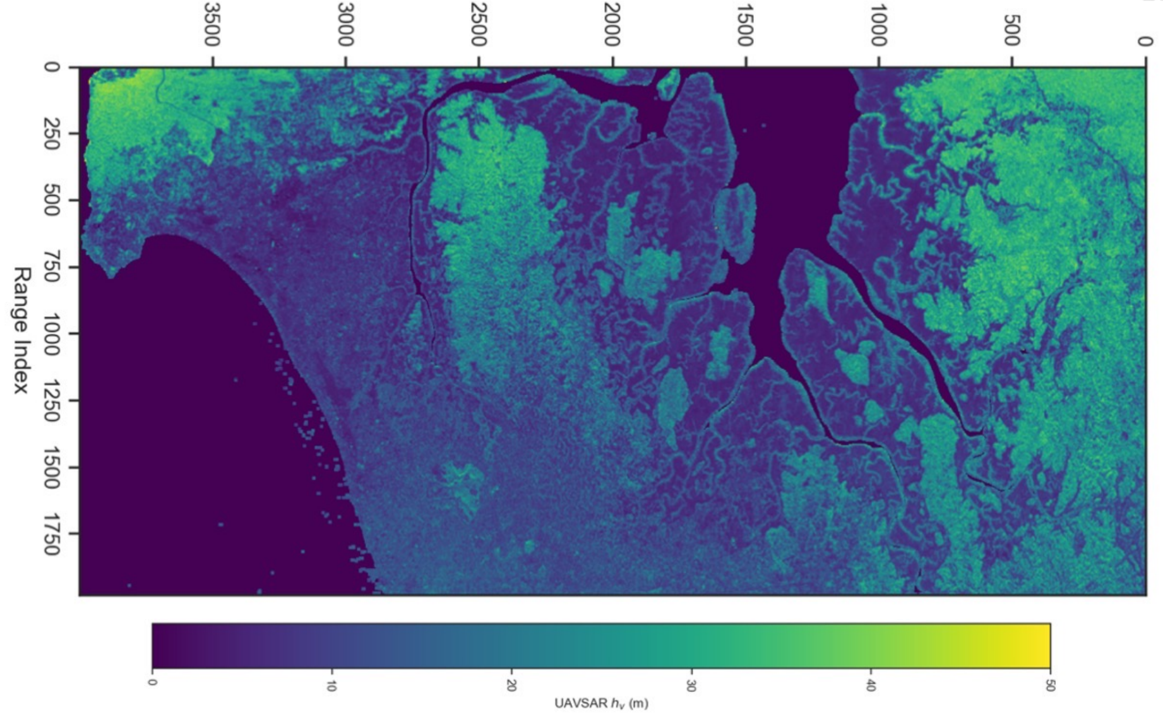


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Figure 4. Triple UAVSAR Baseline Neural Network Forest Canopy Heights for Mondah and Joint Histogram of UAVSAR and LVIS canopy heights. The accuracy of the neural network for Mondah is 4.8-m RMS and is comparable to the RMS difference between airborne LIDAR and the spaceborne GEDI sensors for tall forests like that in Mondah. The UAVSAR data used is L- band which is sufficient to get good canopy height estimates for forests less than 20-m in height as in the case for Berms, but as evidenced by the joint histogram in this figure the inability to see the forest floor results in decreased accuracy for forest above 30-m. Additional data (not shown) indicated that both spaceboren LIDAR (GEDI) and L-band UAVSAR had difficulty estimating accurate ground heights in Gabon forests.

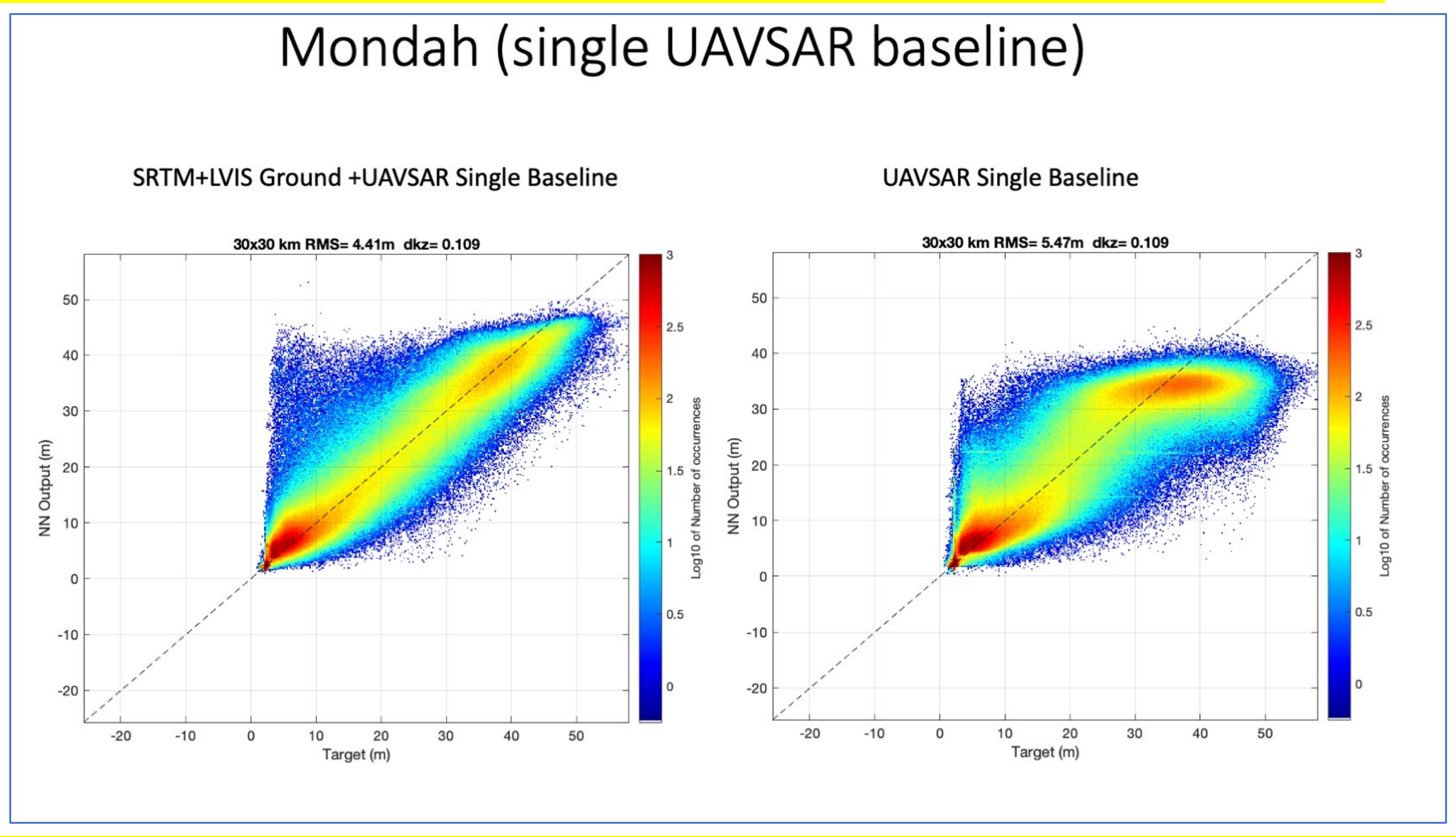

Figure 5. Single Baseline Neural Network Accuracy for Mondah with and without SRTM and LVIS ground height inputs. SRTM (C-band) heights are mid-way between the forest floor and the ground. The difference between the SRTM height and the ground height is highly correlated with forest canopy height. Including this information as input to the neural network results in a joint histogram (left panel) that is accurate at all heights without errors for taller forest such as those in the joint histogram on the right and in Figure 4. Airborne LVIS data cannot be obtained globally, so LVIS ground heights are not available operationally but other ground height sensors such as low frequency InSAR or PolInSAR should be considered. Toward that end we have obtained P- band UAVSAR data which will be examined in a follow-on study.

Background: The remote sensing of forest structure is a complex problem for which many different complementary instruments have been proposed. A review of the current state of the art can be found in [2]. Currently, several different active sensors including LIDAR, TomoSAR (BIOMASS, STV), and PolinSAR (EcoSAR) are being developed in order to obtain more direct three dimensional measurements of forest structure parameters that can be used to quantify the contribution of forest in the carbon cycle, and also support forest management. The UAVSAR airborne experiment, supervised by co-Investigator, Yunling Lou, has provided experimental data with which to evaluate the TomoSAR and PolinSAR concepts.

References

1. Denbina, Michael, Marc Simard, and Brian Hawkins. 2018. “Forest Height Estimation Using Multibaseline PolInSAR and Sparse Lidar Data Fusion.” IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. https://doi.org/10.1109/JSTARS.2018.2841388.
2. Yan Gao et al, “Remote sensing of forest degradation: a review,” Environ. Res. Lett. Vol. 15, 2020, 103001 https://doi.org/10.1088/1748-9326/abaad7

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Clearance Number: CL#**22-4837**
Poster Number: RPC#R22037